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NASA'S SPACE LAUNCH SYSTEM:  
A HEAVY-LIFT PLATFORM FOR ENTIRELY NEW MISSIONS

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The National Aeronautics and Space Administration's (NASA's) Space Launch System (SLS) will contribute a new capability for human space flight and scientific missions beyond low-Earth orbit (LEO). The SLS Program, managed at NASA's Marshall Space Flight Center, will develop the heavy-lift vehicle that will launch the Orion Multi-Purpose Crew Vehicle (MPCV), equipment, supplies, and major science missions for exploration and discovery. Orion will carry crews to space, provide emergency abort capability, sustain the crew during space travel, and provide safe reentry from deep-space return velocities. Supporting Orion's first autonomous flight to lunar orbit and back in 2017 and its first crewed flight in 2021, the SLS ultimately offers a flexible platform for both human and scientific exploration. The SLS plan leverages legacy infrastructure and hardware in NASA's inventory, as well as continues with advanced technologies now in development, to deliver an initial 70 metric ton (t) lift capability in 2017, evolving to a 130-t capability, using a block upgrade approach. This paper will give an overview of the SLS design and management approach against a backdrop of the missions it will support. It will detail the plan to deliver the initial SLS capability to the launch pad in the near term, as well as summarize the innovative approaches the SLS team is applying to deliver a safe, affordable, and sustainable long-range capability for entirely new missions—opening a new realm of knowledge and a world of possibilities for multiple partners. Design reference missions that the SLS is being planned to support include Mars, Jupiter, Lagrange Points, and near-Earth asteroids (NEAs), among others. The Agency is developing its mission manifest in parallel with the development of a heavy-lift flagship that will dramatically increase total lift and volume capacity beyond current launch vehicle options, reduce trip times, and provide a robust platform for conducting new missions destined to rewrite textbooks with the information they deliver, while creating a framework for further collaboration among domestic and international partners, and potentially spurring economic expansion into new markets.

### I. PROGRAM BACKGROUND

Since the 2010 NASA Authorization Act was signed into law, the agency has been moving forward with a space exploration program designed to carry human beings beyond LEO for the first time since 1972, when the Apollo Program concluded its sixth and final landing on the Moon.

The first two elements of this exploration program are the Orion MPCV and SLS. The Orion is a four-person spacecraft designed to support exploration missions to multiple destinations, including the Moon, NEAs, Lagrange points, and Mars. The SLS is a heavy-lift launch vehicle that will transport Orion as well as cargo and other systems and equipment to LEO and beyond.

Orion and SLS fit within a broader U.S. strategy of encouraging commercial launches of crew and cargo to the International Space Station (ISS), while concentrating NASA's exploration systems on missions beyond Earth orbit (BEO).<sup>\*</sup> The SLS and Orion are fundamental building blocks in a capability based architecture designed for long-term human exploration of the solar system. Both Orion and SLS are being designed with enough performance margin and flexibility to support multiple missions and destinations rather than being optimized for one particular mission or architecture.

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<sup>\*</sup> NASA Authorization Act of 2010.  
[http://commerce.senate.gov/public/?a=Files.Serve&File\\_id=20a7a8bd-50f4-4474-bf1d-f0a6a8824b01](http://commerce.senate.gov/public/?a=Files.Serve&File_id=20a7a8bd-50f4-4474-bf1d-f0a6a8824b01).

In accordance with the 2010 legislation—and to leverage NASA's investments in heritage systems such as the Space Shuttle and the Constellation Program—NASA is using several existing or in-development systems to reduce the SLS's design, development, test, and evaluation (DDT&E) cost, risk, and schedule.

## II. VEHICLE OVERVIEW

### I.I Vehicle Description

The SLS vehicle family will start with a lift capability of 70 t to LEO and will evolve to 130 t (Figure 1).

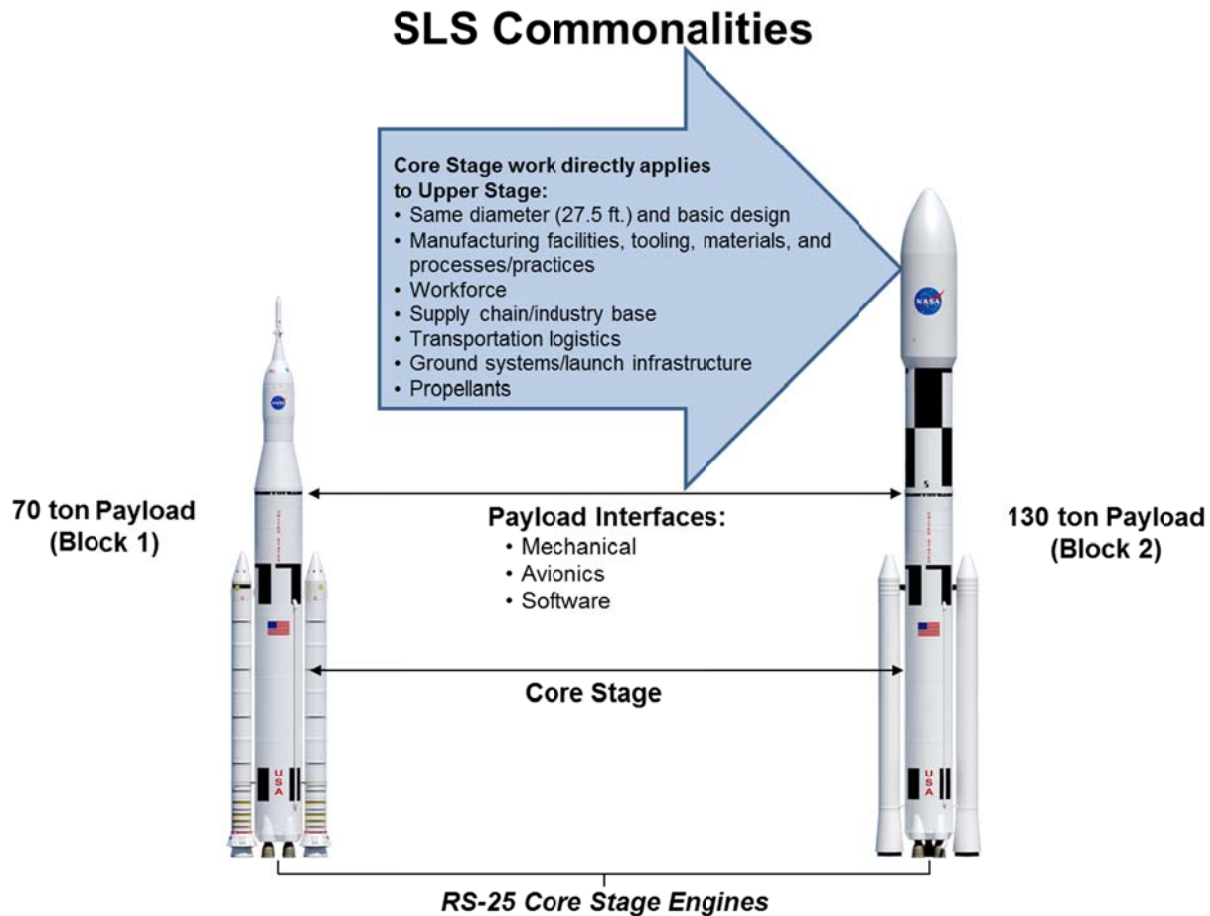


Fig. 1: The 70-t and 130-t variants of SLS will leverage legacy elements from previous NASA programs.

The initial 70-t configuration of the vehicle will consist of an 8.4-meter-diameter core stage powered by four RS-25 liquid hydrogen/liquid oxygen engines, which formerly powered the Space Shuttle and builds on the U.S. state of the art in liquid propulsion. The core stage will be flanked by two five-segment solid rocket boosters (SRBs)—a more powerful version of the four-segment boosters used on Shuttle and developed originally for the Ares launch vehicles. For the first two missions of SLS, a commercial Interim Cryogenic Propulsion Stage

(ICPS) will be used to propel the Orion spacecraft from LEO toward the Moon. The ICPS will provide the in-space propulsion needed until NASA's missions require the J-2X upper stage engine for larger payloads launched BEO, such as to Mars.

While the core stage design, diameter, materials, and manufacturing processes are expected to be constant as the vehicle is evolved, the program plans to replace the five-segment SRBs with more powerful solid- or liquid-propellant boosters, which will be selected through a full and open competition among U.S.-based suppliers. In July 2012 NASA selected six proposals to perform engineering demonstrations of new propulsion technologies under a NASA Research Announcement (NRA) to improve the boosters' affordability, reliability, and performance. Awards are expected in fiscal year 2013.<sup>†</sup> These initial risk-reduction tasks will be followed by a full-and-open competition for DDT&E work leading to an eventual advanced booster selection for the evolved SLS.

## II.II Design Approach

SLS is being designed with three key principles in mind: safety, affordability, and sustainability.

Safety is a top priority for human-rated systems. In the current policy and economic environment, affordability means designing and conducting work within a flat budget for the foreseeable future. This will be achieved by maximizing the use of common elements and existing assets, infrastructure, and workforce while also providing competitive opportunities to develop new systems. Sustainability is the ability of the SLS Program to remain affordable across multiple years and to support multiple missions. Again, SLS will ensure sustainability by leveraging common manufacturing facilities, tooling, materials, and processes/practices; experienced employees; supply chain and industry base; transportation logistics; ground systems/launch infrastructure; and propellants, all while living within its appropriated budget.

NASA's long history of Space Shuttle fabrication, assembly, transportation, and launch operations will help the agency and its contractor partners develop what Yale technologist David Gelernter calls, "a beautiful

machine," one that enjoys "a happy marriage of simplicity and power—with *power* meaning the ability to accomplish a wide range of tasks, to get a lot done."<sup>‡</sup> This philosophy of reducing complexity in design and operations is a key to program success.

## II.III Purpose, Performance, Payload

The 70-, 105-, and 130-t SLS vehicles all fulfill specific, important roles within the exploration architecture.

The 70-t vehicle will prove out the new core stage and integrated stack for the initial exploration missions to the Moon (EM-1 and EM-2) and for scientific payloads beyond Earth orbit.

The 105-ton vehicle has been identified as fitting a potential "sweet spot" for the next set of human missions beyond LEO and will be the first variant to fly with advanced liquid- or solid-propellant boosters (Fig. 2).

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<sup>†</sup> "NASA Selects Space Launch System Advanced Booster Proposals." 13 July 2012  
[http://www.nasa.gov/exploration/systems/sls/advanced\\_booster.html](http://www.nasa.gov/exploration/systems/sls/advanced_booster.html).

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<sup>‡</sup> Gelernter, David. *Machine Beauty: Elegance and the Heart of Technology*. Basic Books, 1998.

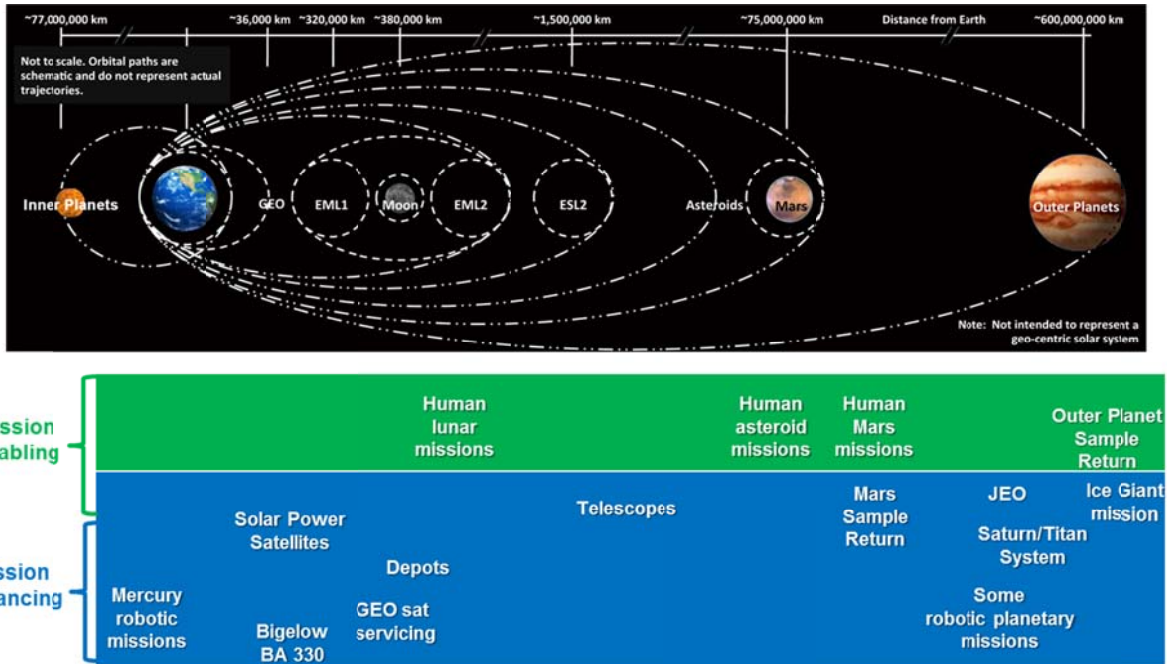


Fig. 2. NASA's internal studies have identified missions where SLS could play an important mission-enhancing or enabling role.

The 130-ton vehicle is being designed as a true exploration-class vehicle, with the performance needed to support human missions to beyond LEO. This SLS configuration will require a new upper stage with one or two J-2X upper-stage engines—a propulsion system that is in developmental testing at NASA's Stennis Space Center.

The SLS flexible family of vehicles is designed with one overarching purpose: to explore beyond Earth orbit with ambitious mass and propulsion requirements. As such, SLS is being designed as complementary to the commercial launch industry capabilities, because its mission is not addressed by the foreseeable commercial market capability (Fig. 3).

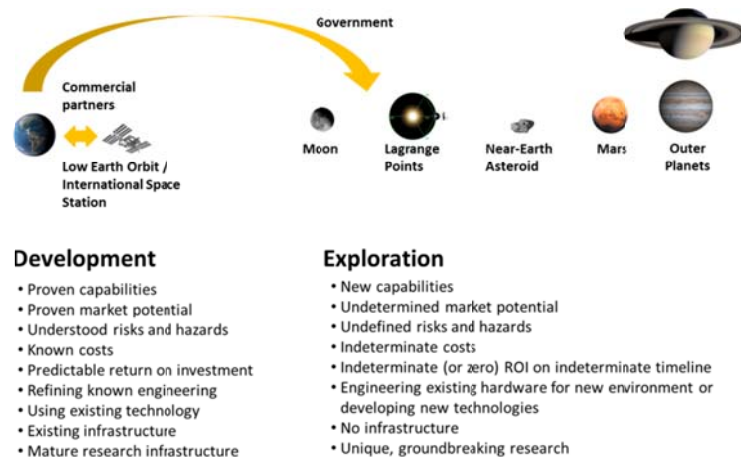


Fig. 3. The LEO-access capabilities of the commercial sector and exploration capabilities of SLS operate in different functional, complementary spaceflight regimes.

The SLS rocket will enable scientists to address some of the most compelling questions imaginable. Design reference missions being addressed through the SLS design process include: LEO, beyond Earth orbit, geostationary orbit, geostationary transfer orbit, lunar vicinity (Lagrange Point 1), and deep space such as to a near-Earth asteroid and Mars. With its superior lift capability, the SLS can expand the interplanetary highway to many possible destinations, providing human and science instruments transportation to revolutionary discoveries.

The SLS rocket will enable NASA to verify the potential of valuable cislunar locations for positioning future advanced space telescopes and observatories, microgravity processing facilities, and orbiting fuel depots to support the construction, fueling, and repair of space systems.

How did the solar system form? Where did Earth's water and organics originate? The SLS rocket can help scientists find these answers — as well as resources to support ever-increasing needs for energy and minerals — on the asteroids that cross Earth's orbit. Potentially hazardous asteroids must be better understood to deploy timely, effective methods for planetary defense, perhaps preventing mass extinctions due to asteroid impacts for the first time in history.

The SLS rocket can take astronauts to Mars and its moons Phobos and Deimos, which are among the most fascinating targets in our solar system. Do they support life as we know it? Can people live there? NASA has learned many exciting things about the Red Planet's environment from the Mars rovers *Spirit*, *Opportunity*, and *Curiosity*. The *Mars Reconnaissance Orbiter* recently helped scientists confirm the seasonal presence of saltwater and raised more questions.<sup>§</sup> In the not-too-distant future, U.S. astronauts may join forces with robots and science probes—which can neither think independently nor directly

detect life on their own—and to experience firsthand a land that has many similarities with our home planet.

The SLS rocket may take explorers back to the Moon to discover the cosmic events that shaped it, Earth, and the inner planets of the solar system. Believed to have been the result of an asteroid strike on the Earth, the Moon has a surface area roughly the size of North and South America. Recently NASA confirmed the presence of water stores on the Moon, opening entirely new possibilities for establishing a way station to further destinations, geological operations, and observatories on its far side.<sup><Jl</sup>

The possibility of conducting missions never before attempted makes this flexible capability attractive to multiple partners. A short list of potential partners and payloads, along with a sample of space exploration advisory committees, includes:

- 1) U.S. Government agencies such as the Department of Defense; Department of Energy; Defense Advanced Research Projects Agency; and National Oceanic and Atmospheric Administration.
- 2) International partners, as reflected in the Global Exploration Roadmap developed by the United States, Canada, Europe, France, Germany, India, Italy, Japan, the Republic of South Korea, Russia, Ukraine, and the United Kingdom.\*\*
- 3) Scientific, engineering, and academic organizations such as NASA's Lunar Science Institute and Optimizing Science and Exploration Working Group, the Lunar Exploration Analysis Group, and the International Lunar Exploration Working Group.
- 4) Emerging commercial partners through NASA's Commercial Crew Development and Commercial Orbital Transportation

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<sup><Jl</sup> National Aeronautics and Space Administration. (2009, Nov. 13). "LCROSS Finds Water on the Moon" [http://science.nasa.gov/science-news/science-at-nasa/2009/13nov\\_lcrossresults/](http://science.nasa.gov/science-news/science-at-nasa/2009/13nov_lcrossresults/)

\*\* *The Global Exploration Roadmap*. International Space Exploration Coordinating Group, September 2011.

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<sup>§</sup> National Aeronautics and Space Administration. (2011, Aug. 4). "Salt Water May Flow on Mars." [http://science.nasa.gov/science-news/science-at-nasa/2011/04aug\\_marsflows/](http://science.nasa.gov/science-news/science-at-nasa/2011/04aug_marsflows/)



Services contracts, preparing the transportation systems that will provide vital supply lines for future explorers.

- 5) Decadal-class science missions described in the National Research Council's *New Worlds, New Horizons in Astronomy and Astrophysics* and *Vision and Voyages for Planetary Sciences in the Decade 2013-2022*.<sup>tt</sup>

#### II.IV Advantages of SLS for Science Payloads

The Apollo program proved the utility of a heavy-lift launch vehicle (HLLV) for human space exploration missions, as they can deliver massive capabilities with a single launch including spacecraft, surface landers/rovers, and propellant for sending these systems beyond Earth orbit. Both the U.S. and its international partners look forward to the next phase of BEO exploration and have identified an HLLV as important to that effort. The 2009 Review of U.S. Human Space Flight Plans Committee (a.k.a. the Augustine Panel) said that an HLLV “combined with the ability to inject heavy payloads away from the Earth, is beneficial to exploration, and it also will be useful to the national security space and scientific communities.”<sup>tt</sup> Furthermore, groups such as the International Space Exploration Coordinating Group (ISECG) recognize the HLLV as a “key enabling technology for any exploration scenario.”

In addition to human exploration activities, SLS also could revolutionize robotic space missions. The primary consideration for most robotic space missions has been the need to fit the payload inside existing launch vehicles, which constrain spacecraft mass and size and often result in complex, origami-type folded designs that increase vehicle complexity and risk. SLS provides enough space to allow designers to relax volume constraints and

concentrate on developing the instruments necessary to accomplish the primary science mission.

Another constraint for current science missions is the limit on characteristic energy (C3) available to send spacecraft to BEO. The additional energy of SLS offers reduced mission time, thereby reducing power requirements as well as the amount of time that scientific instruments are exposed to space (Fig. 4)

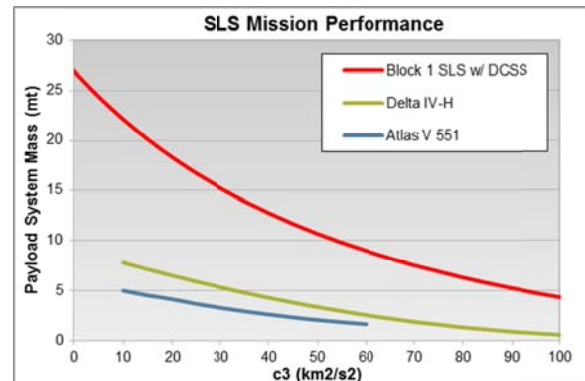


Fig. 4. The C3 curve for the 70-t SLS vehicle shows a decided advantage for science payloads.

While commercial launchers have and will continue to serve as the workhorse for many of NASA’s science missions, the spacecraft often have to make multiple gravity-assist maneuvers around several of the inner planets before reaching the velocity needed to reach outer planets such as Jupiter or Saturn. These maneuvers increase mission times by years and increase risk to onboard instruments because of the extended time in the space environment. Table 1 identifies some of the primary advantages of SLS to robotic science missions.

<sup>tt</sup> Review of U.S. Human Space Flight Plans Committee. “Summary Report,” September 2009.

<sup>ttt</sup> National Research Council of the National Academies. (2011). *Vision and Voyages for Planetary Sciences in the Decade 2013-2022* [http://solarsystem.nasa.gov/docs/Vision\\_and\\_Voyage\\_s-FINAL.pdf](http://solarsystem.nasa.gov/docs/Vision_and_Voyage_s-FINAL.pdf).

Attributes	Outcomes
<ul style="list-style-type: none"> <li>• Volume and mass capability</li> <li>• Fewer origami-type payload designs needed to fit in the fairing</li> </ul>	Increased design simplicity
<ul style="list-style-type: none"> <li>• Fewer deployments</li> <li>• Fewer critical operations</li> </ul>	Increased mission reliability and confidence
<ul style="list-style-type: none"> <li>• High-energy orbit</li> <li>• Shorter trip times</li> </ul>	Less expensive mission operations
<ul style="list-style-type: none"> <li>• Increased lift capacity</li> <li>• Increased payload margin</li> </ul>	Less risk

Table 1: SLS design attributes that can benefit robotic mission design.

The SLS team has been discussing the advantages of HLLV with members of the science community. To take advantage of the mass and volume capacity SLS offers, spacecraft designers and mission planners will need to change their fundamental assumptions about what is possible with a single launch vehicle. However, if put to its greatest advantage, SLS could facilitate single-launch missions to the outer solar system, including first-ever sample return missions to Mars, Jupiter/Europa, and Saturn/Titan.

### III. VEHICLE/PROGRAM STATUS

#### III.I Hardware Progress

The SLS vehicle is on track for a first flight to BEO in 2017. This progress is possible by leveraging NASA's investments in previous programs, including the recently retired Space Shuttle and Constellation Program.

Four complete sets (16 engines) of Pratt & Whitney Rocketdyne (PWR) RS-25 core stage engines were delivered to Stennis Space Center (SSC) in April 2012, along with much of their related propulsion subsystems (Fig. 5).



Fig. 5. RS-25 Core Stage Engines in storage at SSC.

Alliant Tech Systems (ATK) has completed three full-scale static tests of five-segment development motors for the booster systems (Fig. 6), with a qualification motor test scheduled for spring 2013, rounding out the test series necessary to qualify the five-segment booster for flight.



Fig. 6. Development Motor Test #3 at ATK, Promontory, Utah.

The first MPCV Stage Adapter for SLS is being manufactured (Fig. 7) and will fly as part of the first exploration flight test (EFT-1) of an Orion test article in 2014.

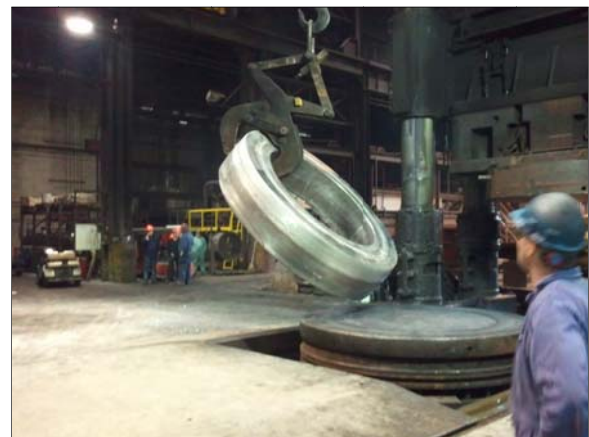


Fig. 7. First Adapter Forging Ring being fabricated at ATI/Ladish, Cudahy, Wisconsin.

The J-2X upper stage engine, which NASA and PWR began developing in 2005, is now well into its first year of powerpack and full engine testing at SSC, accumulating well over 1,000 seconds of firing time (Fig. 8). The J-2X, a modernized, more powerful version of the Saturn V's J-2 engine, achieved a full-power test on only its fourth firing, a record for new rocket engine development.



Fig. 8. J-2X in test stand at SSC.

In addition, a Delta Cryogenic Second Stage (DCSS) is providing the high-Earth-orbit boost for EFT-1. The DCSS will be modified to be the in-space stage (called the Interim Cryogenic Propulsion Stage or ICPS) for the first two SLS exploration missions (EM-1 and EM-2) to the Moon in 2017 and 2021. Lastly, The Boeing Company has delivered the first computers for testing the flight software in Marshall Space Flight Center's Systems Integration Laboratory.

The critical path development item for SLS is the massive core stage structure, which will be the largest single stage ever developed for a launch vehicle. The design philosophy of the SLS is to "design once, fly many times," applying the same core systems and structures from the 70-t vehicle to future, larger vehicles including the 130-t super-heavy-lift launcher. Another advantage of the core stage will be that NASA can use existing or proven processes, facilities, personnel, and materials going forward, which will simplify future production as evolved versions of the rocket are rolled out, in keeping with budget and mission requirements.

NASA is also investing in manufacturing hardware and facilities at Michoud Assembly Facility, taking advantage of work done by experienced development and operational personnel, as well as a one-of-a-kind infrastructure asset.

### III.II Programmatic Accomplishments

All this activity has been occurring within a constrained budgetary environment and reduced workforce. On July 25, 2012, the program passed its combined System Definition Review/System Requirements Review and received permission to move forward toward its Preliminary Design Review, currently scheduled for late 2013.

While moving forward with previous hardware developments, SLS also released its Request for Proposal for the core stage to Boeing on August 1, 2012. NASA Research Announcement (NRA) Contracts will be awarded. The awardees will develop engineering demonstrations and risk reduction concepts for SLS. Additional contracts will be awarded for advanced development of new block upgrades, concept development, and the integrated vehicle; propulsion; manufacturing, structures, and materials; and avionics and software.

The mix of contract mechanisms SLS is using will help NASA take advantage of the experience of legacy systems while also allowing the agency to "spin in" new ideas and technologies to help improve performance and reduce cost.

### III.IV Upcoming Milestones

In the coming calendar year, SLS will undergo a series of important reviews to ensure its progress toward final design. The Preliminary Design Review (PDR) will be conducted for the entire vehicle, as will the PDRs for the booster and core stage elements. The SLS Critical Design Review (CDR) is scheduled for early 2014.

The final design of the ICPS will be down-selected in late 2013, with production to start by the end of third quarter of 2014.



Orion's EFT-1 flight test—with the initial MPCV Stage Adapter providing the launch vehicle interface—will be conducted in early 2014.

Also in the 2013-2014 timeframe, the Ground Systems Development Office will begin construction of new Vehicle Assembly Building platforms for assembling and servicing the SLS.

#### IV. CONCLUSION

Working in an environment full of challenges, the Space Launch System Program continues to advance toward its first launch in 2017 (Fig. 9). The vehicle is being designed to be evolvable and to provide adequate payload margin for multiple missions and destinations across the solar system. The government and industry team is making real progress toward building real hardware and a necessary capability for advancing the next generation of space exploration.



Fig. 9. The SLS will launch for Kennedy Space Center's Launch Complex 39B, starting point for many historic exploration missions.